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<p>The Air Force's policy for determining wartime spares kits is confusing, incomplete, and inconsistent because of complicated terminology and the lack of dialogue between policy makers and those responsible for implementing the policy.</p> <p>This report defines and interprets the terminology, including such terms as pipeline floors, Direct Support Objectives (DSOs), and confidence levels. It identifies several weaknesses in current computational techniques. Those weaknesses include the failure to define operational requirements (DSOs) in a credible and defensible way across the entire wartime scenario, and the inconsistency in the policy concerning cannibalization. Moreover, the role of the pipeline floor quantities in the computation is documented.</p> <p>Potential improvements that address those weaknesses are also described. These improvements are within the existing capability of the Aircraft Sustainability Model, the core set of computational algorithms used in the Air Force's wartime spares requirements system.</p>					
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PREFACE

This briefing is an update of a presentation made to the general session of the Air Force Supply WRM [War Reserve Materiel] Panel (AFSWP) in June 1989. It was presented in response to Action Item Executive Panel 88-6, which calls for an analysis of policy issues related to confidence levels and Direct Support Objectives (DSOs). Since the June presentation, an Air Staff analysis associated with a Defense Management Review (DMR) has addressed many of the same issues. Motivated by the DMR analysis, we have expanded the original AFSWP briefing to include more discussion on the use of pipeline floors to reduce cannibalization actions and the effects of including attrition in the War Readiness Spares Kit (WRSK) computations.

We discuss a number of WRM policy issues and show the effects of alternative policy choices on an illustrative kit -- a 24-aircraft F-15C buy kit drawn from the March 1989 data base. Although we have not used any of the classified rates and factors from the War and Mobilization Plan (WMP), we believe the conclusions we have made based upon these analyses are valid and can be generalized to other weapon systems as well.

Material drawn from this briefing was presented to the Air Force Supply Executive Board (AFSEB) on 1 November 1989.



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EXECUTIVE SUMMARY

CURRENT REQUIREMENTS PROCESS

- **Need consistent and credible approach to requirements**
 - **Operators must determine operational requirements**
 - **Logisticians must implement with judgment**
 - **More dialogue between policy makers and implementers**
- **WRSK policy includes**
 - **WMP scenario, including attrition**
 - **Pipeline floor**
 - **Marginal analysis**
 - **DSO target on Day 30**
 - **Safety levels to achieve target**
 - **No cannibalization**

CURRENT REQUIREMENTS PROCESS

The policy for determining wartime spares kits is confusing, incomplete, and inconsistent because of complicated terminology that is widely misunderstood and the lack of dialogue between policy makers and those responsible for implementing the policy.

We need a consistent and credible approach to wartime spares requirements. This must start with operational requirements that make sense to operators and maintenance personnel. Given the operational requirements, the logistician's job is to achieve a reasonable balance among several objectives — aircraft availability targets, sortie goals, and cannibalization constraints — for a reasonable cost. Finally, the relationship between policy and technology requires better dialogue between policy makers and implementers. Implementers should communicate new techniques to the policy makers so that better policy options can be considered.

Possible improvements to wartime spares policy can best be understood in the context of today's requirements process. In brief, the policy describing a War Readiness Spares Kit (WRSK) computation is as follows:

- Each kit is built to support a 30-day conflict as described in the War and Mobilization Plan (WMP). The WMP provides

the wartime scenario (utilization and attrition rates, sortie length, etc.) and calls for inclusion of attrition in the kit computation.

- Each item has a minimum buy quantity corresponding to the expected pipeline over the scenario. These "floor" quantities are computed without regard to cost.
- Because the demand for each item is variable, the floor quantities alone may not yield sufficient weapon system performance. Aircraft availability targets are specified with a Direct Support Objective (DSO), the number of aircraft that are allowed down (because of lack of spares) on Day 30 of the scenario. The policy guidance is that "safety level" quantities (i.e., spares requirements in excess of the pipeline) are computed using "marginal analysis" to achieve the target DSO.
- Cannibalization of aircraft is not considered to be a source of supply.

MAIN CONCLUSIONS

- Floor policy is not cost-effective
- Surge requirement is not addressed
- Disconnects between policy and implementation
 - Marginal analysis and cannibalization
 - Attrition not included in current implementation
- Potential improvements
 - Treat cannibalization explicitly
 - Set DSO targets
 - Defined throughout scenario
 - Motivated by *operational* requirements
- Results
 - Increased operational capability per dollar
 - Improved credibility for requirements process

MAIN CONCLUSIONS

In addition to explaining some of the complicated terminology, we discuss several interrelated issues: the purpose of the pipeline floor, the failure to address the "surge" (Days 1 through 7 of the WMP) requirement explicitly, and the disconnects that exist between today's policy and implementation of that policy.

The pipeline floor policy is usually justified on the basis of the perception that the floor quantities provide (1) protection against excessive cannibalizations, (2) stability in item requirements over time, and (3) increased capability for any surge portion of the scenario. While these are all valid concerns, they can each be addressed directly in a more cost-effective manner. Current budgetary constraints demand that the Air Force consider modifications to the floor policy — modifications that could significantly reduce cost without sacrificing capability.

Another weakness with current policy is that requirements are driven by aircraft status on Day 30. This preoccupation with the last day results in spares kits that may not fly the first week of the war plan. The Air Force should determine a clear statement of operational requirements *throughout* the scenario.

Some disconnects between the policy and implementation of the policy are the result of incomplete policy guidance. An example is

the requirement for the use of marginal analysis. Marginal analysis can be used in many ways to achieve the DSO objective. The particular implementation used today minimizes cost in part by maximizing cannibalization. This technique is therefore at odds with the stated cannibalization policy. Not all implementation details need to be defined by policy, but the consequences of particular implementation strategies must be well enough understood so that inconsistencies in policy can be avoided.

Contrary to policy, the effects of attrition are not included in today's kit computations. The decision to actually include attrition should not be made without careful attention to the implementation details. Attrition can cause the cost of a kit to go significantly up or down, depending upon the decisions made about DSO targets and the sortie goals of an attrited scenario.

We believe that the spares policy can be refined so that it will result in a greater operational capability and more efficient use of Air Force resources. We can refine it by modifying the pipeline floor policy, dealing explicitly with cannibalization constraints, and defining DSO targets throughout the scenario that are determined by operational requirements. This approach will lead to greater capability and at the same time increase the credibility of the requirement process.

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SECTION 1

BRIEFING OUTLINE

OUTLINE

- **Background: WRSK/BLSS Policy**
- **Terminology**
- **Policy Issues**

OUTLINE

Our presentation is arranged as follows:

- First, we provide background on the perspective the Logistics Management Institute (LMI) brings to this study and to the recent history of wartime spares computations.
- We then review the terminology of War Reserve Materiel (WRM) to provide a common framework for discussion and to preclude common misunderstandings about the usage of technical terms.

- We identify several policy issues and discuss alternatives. These issues include confidence levels, variable support objectives, pipeline floors, the effects of attrition, and the interactions among these issues and the policy on cannibalizations. Our discussion includes detailed comparisons of the results of alternative policies. While we illustrate their effects upon a single F-15C War Readiness Spares Kit (WRSK), we believe the implications of our analyses hold for other weapon systems and for Base Level Self-Sufficiency (BLSS) kits as well.

SECTION 2

BACKGROUND: WRSK/BLSS POLICY

LMI's AIR FORCE RESEARCH PROGRAM

- **Aircraft Availability Model (AAM)**
- **Logistics Analyses**
 - **Requirements**
 - **Management Systems**
- **Aircraft Sustainability Model (ASM)**

LMI's AIR FORCE RESEARCH PROGRAM

LMI is a Federally Funded Research and Development Center -- an FFRDC -- with almost 30 years of experience in logistics research, management, and analyses. In the course of our study program for the Air Force, we developed the Aircraft Availability Model -- the AAM -- a weapon-system-oriented model that relates the expenditures for peacetime operating stock (POS) to aircraft availability rates. The AAM has been used by the Air Staff for more than 10 years and has been modified by the Air Force Logistics Command (AFLC) for use in the POS repairable requirements system (DC41 -- Recoverable Consumption Item Requirements System).

We have complemented our modeling efforts with studies of potential improvements to Air Force systems. In recent years, those studies have included recommendations for developing better demand forecasting techniques and for modifying the base Central Leveling System (D028) to compute stockage levels based on existing inventories.

In the past 5 years, we have concentrated on issues related to wartime spares, and our research has culminated in the development of the Aircraft Sustainability Model -- the ASM.

AIRCRAFT SUSTAINABILITY MODEL

- **History**
 - **Developed by LMI for Air Staff**
 - **Incorporated into REALM (modified Dyna-METRIC)**
- **Advantages of the ASM**
 - **LRU/SRU requirements trade-off**
 - **Budget allocation capability**
 - **Computational efficiencies**
- **Long-Term Potential**
 - **Integrating peacetime and wartime spares**
 - **Building more robust kits**

AIRCRAFT SUSTAINABILITY MODEL

While the ASM was originally developed for the Air Staff, its methodology has been incorporated into the Requirements Execution Availability Logistics Module (REALM) of the Weapon System Management Information System (WSMIS). [Others have described the capabilities of the ASM at Air Force Supply WRM Panel (AFSWP) meetings and WSMIS Program Management Reviews as being "modified" Dyna-METRIC (Dynamic Multi-Echelon Technique for Recoverable Item Control).] The ASM is used in REALM for both requirements and budget allocation.

As it is now implemented in REALM, the ASM offers more capabilities than those of standard Dyna-METRIC. It provides a true line replaceable unit (LRU)/shop replaceable unit (SRU) trade-off logic and a better treatment of constrained funding for budget

allocation. While the ASM is fundamentally compatible with Dyna-METRIC -- its answers can be validated by Dyna-METRIC -- it has a different structure that enables it to provide these increased capabilities with a decrease in computer resource requirements.

Moreover, we have not fully exploited the potential of the ASM. Its ability to balance two or more objectives at once -- our "Cross-Linker" technique -- can be applied to variable support objectives as we discuss in detail later in this briefing book. In the longer term, the ASM would allow the Air Force to integrate peacetime and wartime spares computations and, in a general sense, to provide kits that offer more robust support capability.

POLICY AND TECHNOLOGY

- **Policy implementation**
 - **Interpretation of policy**
 - **Assumptions not always guided by policy**
- **Policy reflects limitations of technology**
- **New technology should influence policy**
- **Overoptimization is a danger**

POLICY AND TECHNOLOGY

In developing the ASM and adapting it to REALM, we have taken a detailed look at the interplay between policy and technology. The way policy is implemented often differs markedly from the way it was intended. For example, the mathematicians and programmers who built the software have interpreted the "pipeline floor" policy in several different ways. Some assumptions on which the mathematical models are based -- such as repair on a first-come, first-serve basis -- are not covered by policy. Other assumptions may be in conflict with the way maintenance and supply actually work. We bring this up to stress that decision makers and policy makers need to be concerned with the way policy gets implemented.

Historically, WRM policy decisions have reflected the limitations of existing technology. An example is the need within Dyna-METRIC to have a confidence-level target -- we will discuss

this in detail later. Correspondingly, when we have a new technology, such as represented by the ASM, we should re-evaluate our policy.

Recently, the Air Force increased its emphasis on optimization -- on maximizing our capability for a given cost or, correspondingly, on minimizing our cost for a desired level of capability. Our warning here is simply that it is possible to over-optimize. As we sharpen our techniques for solving the problems we know how to solve, we must maintain more vigilance and concern about the problems we do not even address. For example, while making our WRSK computations "leaner" with respect to the indenture trade-off, we have given ourselves less flexibility with respect to the many uncertainties of the wartime scenario. We, the logisticians, need to remember that, while it is good to be smart, it is possible to be too smart!

WRSK COMPUTATION HISTORY

- **Conventional Kit**
 - **Expected demands only**
- **D029 Marginal Analysis**
 - **Variability in demand**
 - **Weapon system perspective/DSO**
- **Dyna-METRIC**
 - **"Optimal" solutions**
 - **Introduction of confidence level**
- **Aircraft Sustainability Model (modified Dyna-METRIC)**
 - **Improvements with respect to indenture, constrained funding**
 - **Potential of Cross-Linker**

WRSK COMPUTATION HISTORY

The connection between technology and policy is illustrated by the recent history of how we compute WRSKs. We started with the simplest of computations – compute the average number of demands for each item and buy that many. We now call that kit the “conventional” kit. This computation ignores variability in either demand or repair capability.

We added sophistication by using marginal analysis techniques. Specifically, given the pipeline floor – the conventional kit quantity for each item – marginal analysis, as practiced in the WRSK/BLSS and Authorization Computation System (D029), attempts to find the least-cost mix of additional spares (safety level) needed to attain a specific capability. Actually, we expressed the specific, or target, capability in terms of two constraints: the number of allowable system backorders and a target number of allowable downed aircraft. The latter measure resulted in the DSO target.

Dyna-METRIC technology, then, enhanced the marginal analysis capability, notably by recognizing the difference between LRUs and their constituent SRU subassemblies. However, Dyna-METRIC requires the user (and therefore the makers of WRM policy) to worry about target *probabilities*, referred to as *confidence levels*. The entire notion of confidence level was an invention of the implementers – the mathematical modelers – and not of the policy makers.

The ASM, which embodies the increased capabilities already discussed, is the most recent technology. Its capabilities allow us the chance to re-examine our policy. In particular, the potential of our Cross-Linker technique is such that we can – and should – address the idea of variable support objectives; that is, support objectives that vary over time.

TODAY'S WRSK POLICY

- Given a 24-PAA squadron with a 30-day tasking
- Compute
 - Pipeline "floor" quantity for each item
 - Buy using marginal analysis techniques
 - Stop at availability objective:

$$\text{ENMCS} = \text{Expected (NMCS)} = 6$$

$$\text{or FMC} = 24 - \text{ENMCS} = 18$$

$$\text{or Availability} = 75\%$$

TODAY'S WRSK POLICY

Before reviewing the WRM terminology in detail, let's look at the way we build a WRSK today. Suppose we have a squadron with 24 Primary Aircraft Authorized (PAA) and a particular 30-day tasking as given in the War and Mobilization Plan (WMP). A minimum buy quantity -- the pipeline floor -- is computed for each item. Given the floor quantities, "safety level" spares are added. We stop buying when we reach our goal -- the goal expressed as having no more than 6 aircraft down (due to supply) on Day 30. That is what a DSO of 6 means; to buy enough stock to ensure that,

on average, the expected number of not mission capable for supply (ENMCS) aircraft does not exceed 6.

By the way, the DSO is now commonly interpreted as a percentage: A DSO of 6 per 24 PAA is translated to mean that any size squadron should have a corresponding 25 percent DSO target. Equivalently, a DSO of 6 means that 18 aircraft are fully mission capable (FMC), or that our aircraft availability is 75 percent.

TODAY'S WRSK IMPLEMENTATION

- Assumptions
 - Single, fixed scenario – no attrition
 - Known demand distributions
 -
 -
 -
- Buy procedure
 - Pipeline floor quantity for each item
 - Buy parts in the order that maximizes $\Pr(\text{NMCS} \leq 6)$ per dollar
 - Stop buying when $\Pr(\text{NMCS} \leq 6) = 0.80$

TODAY'S WRSK IMPLEMENTATION

We have to make many modeling assumptions to implement the WRSK computation. Attrition, while included in the WMP, is not used in today's WRSK computation. Other assumptions involve specific treatment of variability in demand and include a number of perhaps questionable assumptions about the repair process (for example, infinite repair capacity, or the absence of priority repair).

As previously noted, WRSK policy calls for the use of marginal analysis techniques to buy safety level above the pipeline floor. Marginal analysis implies a buying rule -- a strategy for the *next buy* -- that is prioritized in terms of *maximum benefit per dollar*. In Dyna-METRIC or ASM implementation, we use $\text{Pr}(\text{NMCS} \leq 6)$ as that measure of benefit. This is not guided by policy at all. In

particular, the effects of using DSO in this way as a buying rule parameter are, in our view, largely unknown to the logistics community. We discuss these effects later.

The policy is clear, however, about the stopping rule, but the implementation is different from the policy. The policy goal is to obtain an ENMCS of 6 (for a 24-PAA squadron). The actual implementation uses a different measure -- the probability, or confidence level, of 6 or fewer aircraft being down (for reasons of inadequate supply). Current practice is to stop when this probability is at least 0.80. We discuss the implications of this implementation procedure later.

QUESTIONS

- **Policy**
 - What does the pipeline floor provide? Is it cost-effective?
 - How do we choose DSO? Should the DSO vary by day?
 - Should attrition be included in the WRSK computation? How?
 - What is the cannibalization policy?
- **Implementation issues**
 - What is the right buying rule? What do we buy next?
 - Can the stopping rule implementation match the policy?

QUESTIONS

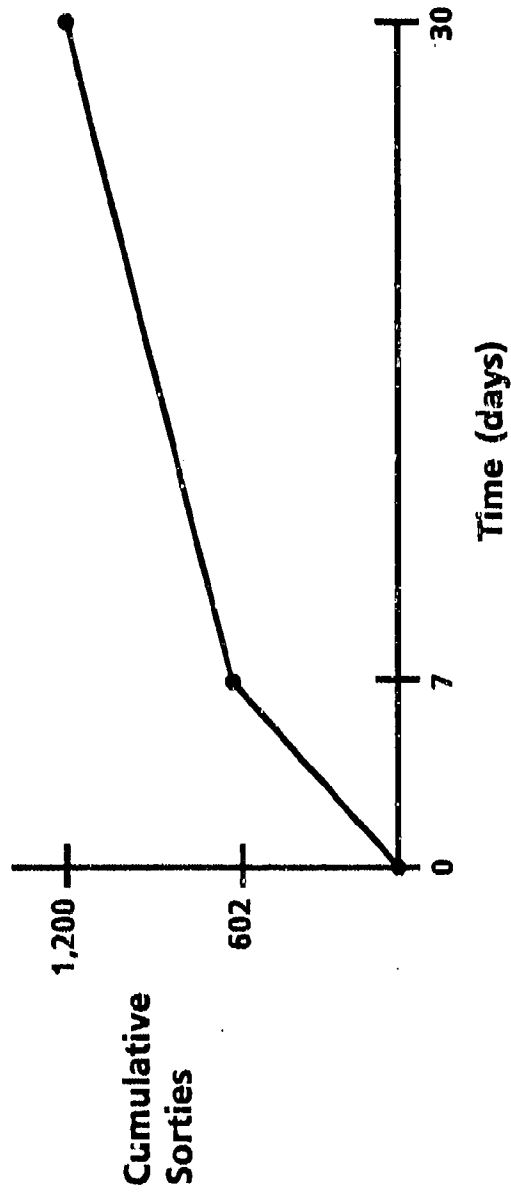
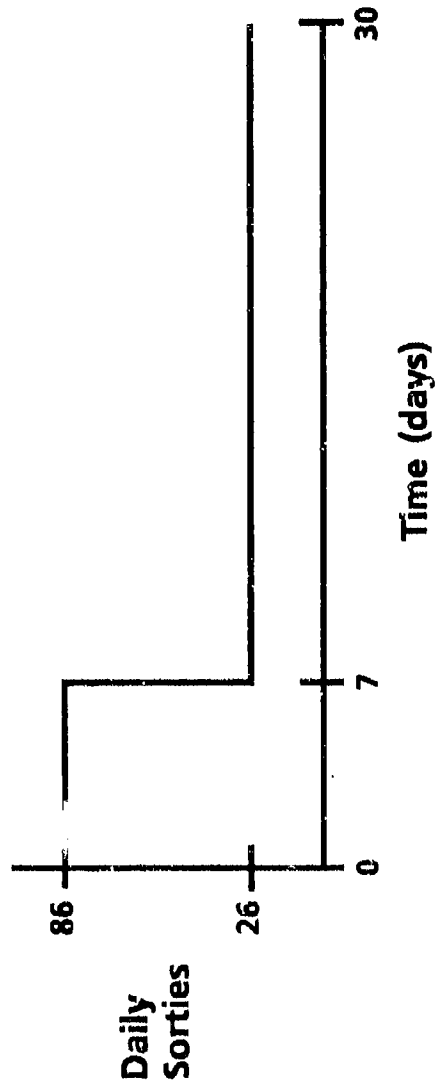
The description of current WRSK policy and today's WRSK implementation suggests many questions. What is the value of the pipeline floor quantity? Why don't we have targeted DSOs for other days? Why is attrition ignored? Is the cannibalization policy consistent with the WRSK computation? Is 0.80 a suitable confidence-level target?

Terms such as pipeline floors, confidence levels, DSOs, and aircraft availability rates can be confusing. We will spend some time reviewing their definitions and the relationships among them.

SECTION 3

TERMINOLOGY

SAMPLE SCENARIO



Average Sortie Duration = 2.0 hours, 24-PAA squadron

SAMPLE SCENARIO

This chart shows a notional 30-day wartime flying schedule. The typical wartime Air Force tasking for tactical aircraft calls for an initial "surge" period (usually 7 days) of high flying levels. The numbers used here (86 sorties per day for the surge and 26 thereafter) were chosen for the convenience of the arithmetic.

The WRSK computation does not take into account any variations in this schedule. No consideration is given to the possibility that the surge period could be longer than planned nor to any variability in sortie durations. Furthermore, this computation makes no allowance for aircraft lost through attrition or battle damage.

PIPELINE COMPUTATION: RR LRU

- Consider a control box with (fictional) data:
 - Demand rate - 0.00125 per flying hour
 - Maintenance concept - remove and replace (RR)
- Pipeline on Day 30 = expected (mean) number in resupply
 - = (demand rate) × (30-day flying hours)
 - = 0.00125 × 2,400
 - = 3.0

PIPELINE COMPUTATION: RR LRU

Consider a hypothetical component -- say a control box -- with the indicated characteristics. The pipeline for the component is defined to be the average number in resupply for a particular point in time. In general, resupply has several segments: base repair, en route from the depot, on order from the manufacturer, etc. In our context, no resupply of any form takes place for 30 days. Therefore, the pipeline on Day 30 is the total expected number of demands over the 30-day period. Assuming a sortie duration of 2 hours per sortie, there would be 2,400 total flying hours over the 30-day period. The resulting pipeline is calculated to have a value of 3.0, as shown.

Note: While existing Air Force policy [Air Force Regulation (AFR) 400-24, "War Reserve Materiel (WRM) Policy," 28 November 1986] refers to this algorithm as a pipeline floor computation, it is in some ways a nonstandard use of the term "pipeline." Pipeline traditionally refers to items in resupply, and we are considering an instance where there is no resupply. Nonetheless, this has become a common usage for pipeline in the context of WRSK computations.

PIPELINE COMPUTATION: RRR LRU

- Consider a computer with (fictional!) data:
 - ▶ Demand rate – 0.01154 per flying hour
 - ▶ Maintenance concept – remove, repair, and replace (RRR)
 - ▶ Repair setup time – 2 days
 - ▶ Repair time – 5 days (constant)
- Pipeline on Day 30 = expected (mean) number in resupply
 - = (demand rate) × (Day 26 – 30 flying hours)
 - = 0.01154×260
 - = 3.0

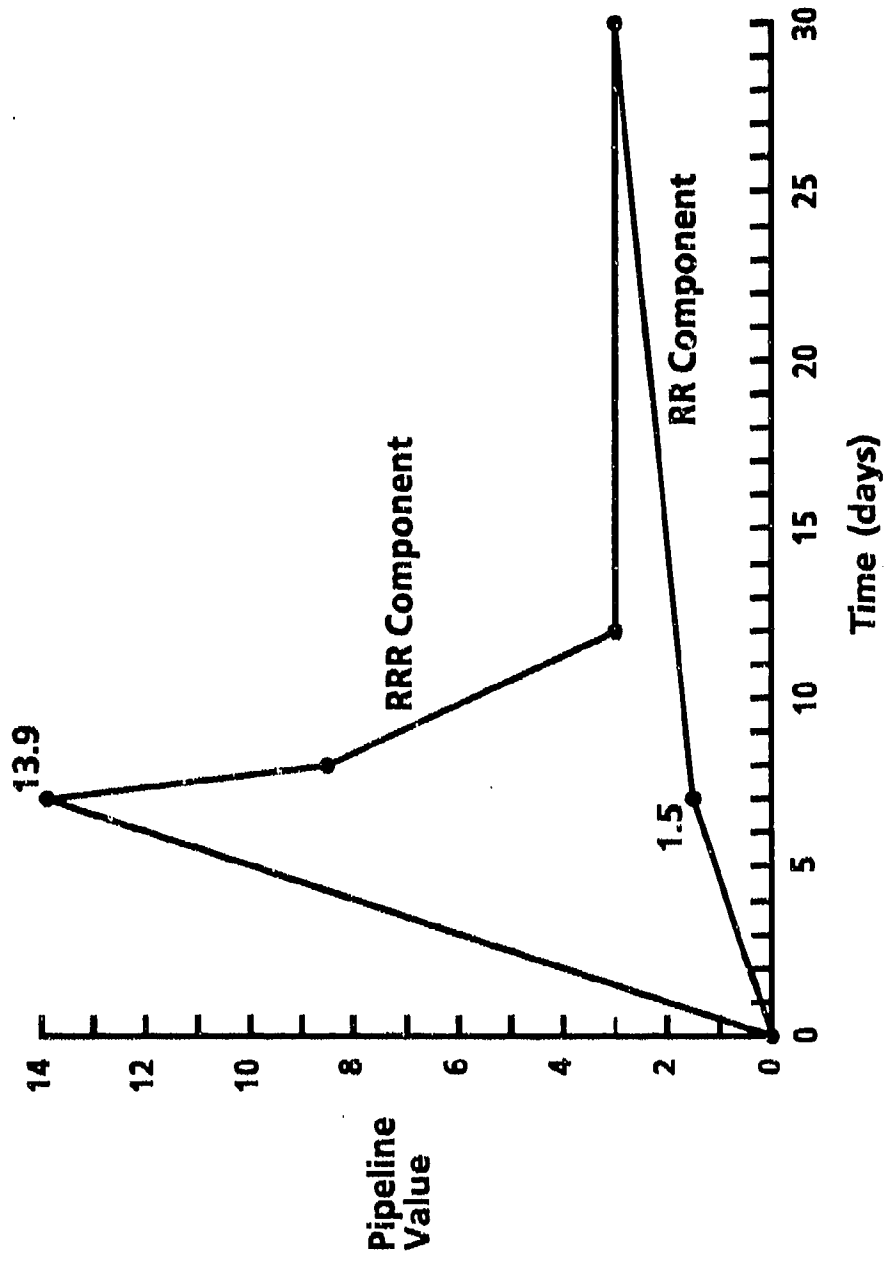
PIPELINE COMPUTATION: RRR LRU

To compute the pipeline value for an LRU that can be removed, repaired, and replaced (RRR), we use similar data for a hypothetical computer but with the assumption that each failure can be repaired in exactly 5 days (with a 2-day setup time at the beginning of the scenario). The pipeline on Day 30 is then the sum of all failures occurring between Day 25 and Day 30 since by Day 30

any failure prior to Day 26 has been repaired and returned to service.

The well-chosen parameters for this example lead again to a pipeline value of 3.0 on Day 30. The pipeline quantity varies over time. We show this variation on the next chart.

PIPELINE DYNAMICS



PIPELINE DYNAMICS

While both components illustrated - RR control box and RRR computer - have pipeline values of 3.0 on Day 30, the dynamics over the 30-day scenario are quite different. This graph shows the day-by-day pipeline values for each component.

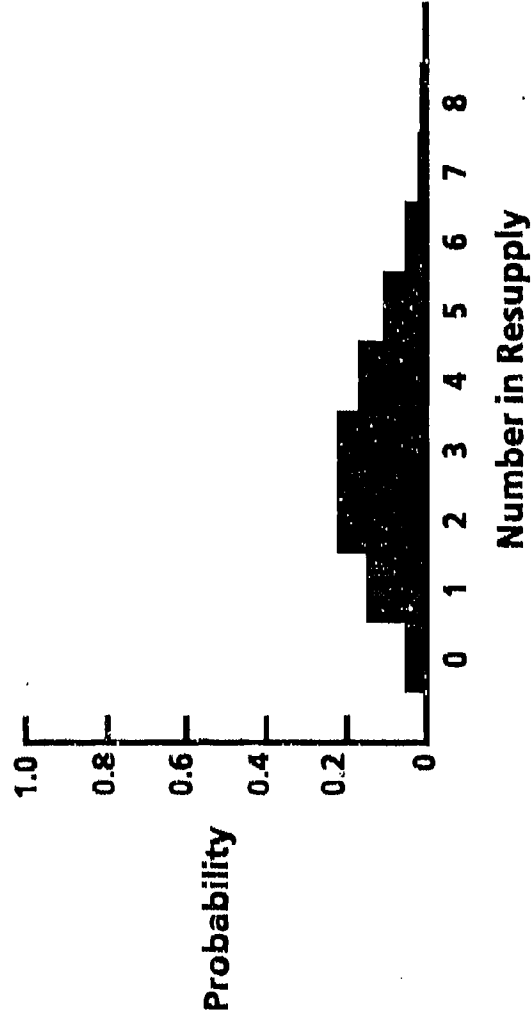
The RR component has an ever-increasing pipeline, representing the lack of all resupply. For a RR item, pipeline equals demand. Thus, the component will, on average, ground three aircraft on Day 30 (and do no worse than that earlier).

The up-and-down shape of the RRR pipeline shows the effects of repair capability. After Day 7 (recall an assumed 2-day setup plus 5-day repair time), maintenance completes repairs faster than our break rate. The effects of the surge are washed out by Day 12 (a

repair time after the surge). From that day onward, we expect to have three items in repair.

The pipeline floor, as described in AFR 400-24, is defined to be "the expected number in resupply over the support period." This graph shows that definition to be far from clear. The policy has been consistently interpreted to mean the peak pipeline value over the scenario. Thus, the minimal buy quantities for our RR control box and RRR computer would be 3 and 14, respectively. Even though our RR control box grounds at the most three aircraft and we are allowing six aircraft (the DSO) to be down, the floor policy forces a minimum buy of three, regardless of cost. We return to the ramifications of this policy later.

DEMAND VARIABILITY



Poisson Distribution with Mean Demand = 3.0

	Number in Resupply								
	0	1	2	3	4	5	6	7	8
Probability	.05	.15	.22	.22	.17	.10	.05	.02	.01
Cumulative probability	.05	.20	.42	.65	.82	.92	.97	.99	1.00

DEMAND VARIABILITY

Remember that the pipeline value is the *average* number in resupply. The actual number in resupply is a random variable; that is, a number that takes on a range of values with various probabilities.

This table and the associated histogram show the variability in demand for a component with a mean demand of 3. For either of our two sample components, the actual number in resupply, on Day 30, has this distribution. Even though the average value is 3, the probability of exactly 3 is only 0.22, while the probability of 3 or fewer is 0.65.

This variability is a consequence of the assumption of Poisson demands. The Air Force assumes, by policy, that components fail during wartime according to a Poisson distribution. The Poisson distribution has the property that its variance equals its mean, or,

equivalently, that the variance-to-mean ratio, VMR, is equal to 1. Empirical data indicate that many components have greater variance; interestingly, VMRs greater than 1 are often used in peacetime computations. Does this mean that we are more certain of demand patterns in wartime than in peacetime?

We are not so much interested in the mathematics of demand variability, but in the consequences of this variability upon our kit computation.

The difference between our spares levels and our pipelines determines our backorders — "holes" on aircraft. The number of holes determines the number of FMC aircraft. We are headed toward a discussion of the relationship between spares levels and FMC aircraft.

MEASURES OF SUPPLY PERFORMANCE

Fill Rate	= percentage of demands upon supply that are satisfied
Expected Backorders (EBOs)	= average number of holes on aircraft – number of MICAPs
Confidence Level	= probability that NMCS \leq DSO
Expected Not Mission Capable Supply – ENMCS	= average number of aircraft down for supply – assumes maximum cannibalization
Aircraft Availability	= average proportion or percentage of aircraft that are FMC (not NMCS)
Expected Sorties	= number of sorties that can be achieved with available FMC aircraft

MEASURES OF SUPPLY PERFORMANCE

The way we measure the ability of the supply system to perform its mission has evolved, as indicated here.

The traditional measure of stockage effectiveness — the item fill rate — tells us the percentage of time that demands made upon the supply system are filled. The problem with that measure is that it conveys very little about the status of the end item, the airplane.

Expected backorders — EBOs — the average number of aircraft holes, summed across all the aircraft, are certainly related to the ability of the squadron to perform its mission. Each backorder renders the aircraft not mission capable; i.e., it results in a "MICAP" in standard Air Force jargon. We use the terms backorders and MICAPs interchangeably throughout this briefing book. Backorder distributions are combined to produce the next three measures shown:

- *Confidence Level.* The probability that DSO or fewer aircraft have a supply hole.

- *ENMCS.* The average number of aircraft down for supply. (Note this is not the standard usage of ENMCS as a measure of *engine* supply performance.) The calculation of ENMCS assumes maximum consolidation of holes onto as few aircraft as possible. This is the maximum cannibalization assumption.
- *Aircraft availability.* The proportion or percentage of aircraft that are FMC (i.e., not NMCS). ENMCS and aircraft availability are directly related. A 24-PAA squadron with an ENMCS of 6 has 18 available aircraft, or an availability of 75 percent.
- *Expected sorties.* The number of sorties that can be generated with the FMC aircraft. Sortie generation calculations depend on turn rates — the number of times each day an aircraft can reasonably be expected to fly.

Let's consider how these measures perform for a simplified example.

SUPPLY PERFORMANCE: BUY THE PIPELINE

Identical LRUs, Pipeline = 3, Spares = 3

Number of LRUs	Fill Rate	EBOs (MICAPs)	Confidence Pr(NMCS \leq 6)	ENMCS	Availability
1	42%	0.67	0.9989	0.67	97.2%
2	42%	1.34	0.9978	1.18	95.1%
100	42%	67.21	0.8958	5.12	78.6%
500	42%	336.06	0.5768	6.45	73.1%

SUPPLY PERFORMANCE: BUY THE PIPELINE

In Line 1 of this table, we assume that the aircraft has exactly one component (LRU) and that component has a pipeline of 3. Therefore, the distribution of demands is as indicated earlier. In addition, suppose that we "buy the pipeline"; that is, suppose that we have a stock level equal to the pipeline value of 3. What do our performance measures indicate?

The probability that a demand upon supply is filled is the probability that at least one spare is "on the shelf." This is equivalent to the cumulative probability that 2 or fewer spares are in resupply — shown to be 0.42 in a previous chart (page 16).

The backorder distribution is derived as follows: with a probability of 0.65, there will be 3 or fewer demands (0 backorders); with a probability of 0.17, there will be 4 demands (1 backorder), etc. This computes to an expected number of backorders of 0.67. Since only one component is involved, an average of 0.67 aircraft will be down because of supply (ENMCS). The confidence level, or probability that 6 or fewer aircraft are down, corresponds to the

probability of 9 or fewer demands. The 0.67 ENMCS represents an availability of 97.2 percent.

The subsequent lines of the table correspond to aircraft with 2, 100, and 500 components (LRUs); for all components, the pipeline is 3. We do not have to see the detailed mathematics to discern the pattern as the complexity of the aircraft increases.

We make three observations: first, the fill rate remains constant; second, backorders go up proportionally to the number of components; and third, the three weapon system measures show degraded performance, but not nearly linearly, as the number of components increase. Note, for instance, that with 500 components, we have an ENMCS of 6.45 (assuming maximum cannibalization or consolidation of holes) and only a 58 percent chance of achieving our $DSO = 6$ target. Since we have not yet hit our ENMCS target, we would, by Air Force policy, have to supplement the pipeline floor buy. We do this with marginal analysis.

MARGINAL ANALYSIS

- What do we buy next?
 - ▶ Biggest "bang per buck"
 - ▶ No policy guidance
 - ▶ We use confidence level: $\Pr(\text{NMCS} \leq \underline{6})$
- When do we stop?
 - ▶ By policy: when $\text{ENMCS} = \text{DSO}$
 - ▶ We use confidence-level target: 0.80 for most kits

MARGINAL ANALYSIS

Marginal analysis is the generic technique that maximizes the "bang per buck." In our context, having bought the pipeline floor, we use marginal analysis to attempt to buy the least-cost mix of spares in the order that maximizes our measure of merit (the bang).

How do we measure the bang? The Air Force has no policy on this point. It would be logical to maximize availability or, equivalently, to minimize the ENMCS. The actual implementation of marginal analysis, as performed by Dyna-METRIC or the ASM, finds confidence level a more mathematically tractable measure. (The reasons confidence level is more tractable relate to the "inseparability" of ENMCS as a mathematical formula. Marginal analysis techniques will result in optimal solutions only if the measure of merit is "separable," and ENMCS is not.)

For any set of spares levels, we buy next that item that yields the greatest increase in confidence per dollar spent. That is our buying rule. When do we stop buying? Air Force policy says we stop when the ENMCS equals the DSO, but currently we stop our kit requirement computation when our confidence level is 0.80. If, instead, we are trying to buy the best mix of spares for a fixed level of funding (the budget allocation problem), we stop when we are out of dollars.

Now we look at a specific example of the WRSK requirement, computed in accordance with existing policy and guidelines.

WRSK REQUIREMENT: F-15C EXAMPLE

Kit Serial = 0F015C0R2460, 398 LRUs, 439 SRUs

Buy	Cost (millions)	Confidence (DSO = 6)	Resulting ENMCS	Resulting MICAPs
Floor Only	\$33.9	17%	8.3	330
Total	\$38.9	80%	5.6	234

WRSK REQUIREMENT: F-15C EXAMPLE

This table shows the WRSK requirement, as determined by the ASM for a 24 PAA F-15C WRSK (Serial Number 0F015C0R2460). This kit is highly indented, with 398 LRUs and 439 SRUs. (This is a *buy* kit, not a *contingency* kit. Buy kits contain data for all components installed on the weapon system. Not all items have a 100 percent application. An application percent of less than 100 can lead to a distortion in the cost "savings" associated with alternative kits.)

The cost of the conventional kit (pipeline floor quantities only) is shown to be \$33.9 million. Notice that if we buy the pipeline floor only, on Day 30 we will have 8.3 aircraft down because of supply and only a 17 percent chance of having 6 or fewer aircraft down. Since the goal is to have no more than 6 aircraft down for supply, the floor quantities are not enough. The subsequent marginal analysis bought \$5.0 million of safety-level spares. That \$5.0 million was determined to be the least cost, given the pipeline

floors, for obtaining 0.80 confidence (expressed in the table as a percent).

Today's kit results in an average of 5.6 aircraft down for supply on Day 30. We show the MICAP value (234) because of its implications concerning cannibalization. The Coronet Warrior exercises conducted by the Tactical Air Command (TAC) suggest that there are many additional cannibalization actions for items that are not in the kit range. With this caveat, we use the MICAP value as a surrogate for cannibalization actions.

Another subject deserving scrutiny, but not included here, is the disconnect between the gross (no starting assets) requirements that are computed with buy kit rates and factors and the subsequent buy requirements that emerge after applying assets and factoring by percent application.

SECTION 4

POLICY

POLICY ISSUES

ISSUE 1: Pipeline Floor

ISSUE 2: Setting the DSO

ISSUE 3: Setting the Target

ISSUE 4: Including Attrition in WRSK

POLICY ISSUES

We are now going to address four specific issues:

- First, what does the pipeline floor buy us in terms of support capability?
- Second, what is the DSO and how should it be set?
- Third, what is our requirements target? Given a DSO has been set as an NMCS tolerance, are we satisfied with a DSO number of aircraft down *on average* or do we require greater probability – confidence – of achieving that goal?

- Finally, why is attrition omitted from the requirements computation and what are the effects of attrition upon the requirement?

We deal with each item in turn but note that the issues are intertwined, especially the relationship between confidence levels and DSOs. Moreover, we deal with these issues in the context of our perspective on policy and technology. In part, the capabilities of the ASM have influenced the observations we make on the above issues.

ISSUE 1: PIPELINE FLOOR

- **AFR 400-24 guidance**
 - ▶ **"Expected value quantity for the specified support period"**
 - ▶ **Interpreted to be the "peak" quantity**
- **Reasons for the floor**
 - ▶ **Constraint on cannibalization actions**
 - ▶ **Stability of requirement**
 - ▶ **Protection for RRR items during surge**
 - ▶ **Hedge against peacetime shortfalls**
- **AFSWP rejected any change to floor policy**

ISSUE 1: PIPELINE FLOOR

The pipeline floor policy, while not completely defined by AFR 400-24, has been consistently interpreted to mean the peak pipeline over the entire scenario. The following reasons have been given for the pipeline floor policy:

- First, a kit purchased under a pipeline floor policy will cause fewer cannibalizations than will a kit purchased without a floor. Guidance on the use of cannibalization is conflicting. AFR 400-24 states that "It is Air Force policy that cannibalization is not acceptable as an alternative to stockage of at least expected value quantities. Cannibalization is not to be considered a source of supply, but rather an emergency, last resort means of reducing the mission impact of out of stock conditions." That statement is somewhat contradictory to the existence of the DSO; if 6 aircraft are going to be down, how do we benefit by having them down because they are missing a few parts rather than because they are missing many parts? Furthermore, the ENMCS calculation is highly dependent upon a maximum cannibalization assumption.

- Second, another reason given for the pipeline floor is that floors provide stability in the requirement from year to year. Most of the instabilities seem to be caused by changing rates and factors that would also cause the floors themselves to be unstable. We believe that an asset-based

requirement (as opposed to the zero-based method we use today) would result in greater stability without relying on the floors.

- Third, the floor quantities — particularly the peak floor for RRR items — provide protection against our ability to meet the sortie goal of the surge period. We show that, using the ASM, the surge requirement can be explicitly addressed as part of the computational algorithm.
- Fourth, wartime spares are used to make up for peacetime supply/repair deficiencies. While this is not really a *reason* for the pipeline floor, some would argue that the floor policy provides the "fat" that the kits need to enable the units to fulfill their peacetime objectives. Our only comment is that wartime spares policy should not be used to offset peacetime supply deficiencies.

A discussion of pipeline floors at the June 1989 AFSWP led to a rejection of any modification of existing policy. The stability and cannibalization issues were cited as the primary reasons. We bring this up again because of the budgetary pressures that are being brought to bear on WRM — pressures that may force a reconsideration. The floor policy is very expensive, as we now show.

THE COST OF THE FLOOR

Method	Cost (millions)	Confidence	ENMCS	MICAPs
Without Floor	\$31.1	0.80	5.7	407
Today's Kit	\$38.9	0.80	5.6	234

THE COST OF THE FLOOR

This table shows the cost with and without the floor. With the floor, and a $DSO = 6$, 80 percent confidence can be achieved for \$38.9 million. Without the floor, the same confidence costs only \$31.1 million. This is the least possible cost for achieving the 80 percent confidence goal. The floor quantities make the kit more expensive (for the same confidence).

It is clear, however, that eliminating the floor results in significantly more MICAPs – and therefore more cannibalization actions. The question: Is the \$7.8 million a cost-effective way of constraining cannibalizations?

Let's look at some specific items that drive this cost increase.

WHAT IS A CANNIBALIZATION WORTH ?

NSN	Cost	Pipeline Buy
5841011927573	\$548,711	1
5841011936383	\$534,200	1
5841012677731	\$578,584	2
5841012700523	\$716,299	2

WHAT IS A CANNIBALIZATION WORTH?

Here are four airborne radar equipment items from our F-15C kit, all of which have a zero requirement under a no-floor computation. Consider our first item - National Stock Number (NSN) 5841011927573 - a low demand item with a 30-day demand of only 1. The pipeline floor policy requires a buy of 1 - regardless of cost! In this case, the cost exceeds half a million dollars. Moreover, this purchase will save at most 1 cannibalization.

The pipeline floor for all four items costs \$3.7 million and saves at most six cannibalizations. In total, 26 items, costing

\$6.8 million, were bought solely because of the pipeline floor policy. There are cheaper ways to minimize cannibalization actions, as we now show.

Note: The costs shown here are *procurement* costs that potentially preclude cannibalization actions. We are not addressing any direct labor costs associated with cannibalization. The question of how many cannibalizations can be performed with the planned deployment of maintenance personnel is a real issue, but hard to quantify.

PIPELINES AND CANNIBALIZATIONS

- Pipeline floor
 - ▶ Disregards cost
 - ▶ Inefficient cannibalization control
- Today's buying rule: Maximize $P_1(NMCS \leq 6)$
 - ▶ Not guided by any policy
 - ▶ Insensitive to cannibalization actions
- Alternative buying rule could control cannibalizations

PIPELINES AND CANNIBALIZATIONS

Buying the pipeline floor reduces cannibalizations only because buying anything "extra" improves any measure of effectiveness. If controlling cannibalization actions is a goal, there are ways to do that directly. Nothing about the floors themselves inherently controls cannibalizations.

Today's buying rule is also insensitive to cannibalizations in this sense: a model that optimizes with respect to $\Pr(\text{NMCS} \leq 6)$

effectively takes six FMC aircraft, breaks them down into component parts, and considers those parts as spares "on the shelf." Obviously, this approach will result in lots of cannibalizations.

However, we could think of the six aircraft as a cannibalization control parameter. Let's see what happens as this parameter varies.

CONTROLLING CANNIBALIZATION

Buying Rule	Cost (millions)	ENMCS	MICAPs
Pr(NMCS \leq 6) Floor Only	\$34.0	5.4	385
	\$34.0	8.3	330
Pr(NMCS \leq 4)	\$34.0	5.3	303
Pr(NMCS \leq 2)	\$34.0	5.8	185

A Cannibalization Support Objective (CSO)
can limit cannibalization actions.

CONTROLLING CANNIBALIZATION

This table shows the pipeline floor buy of \$34 million and the results of three different buying rules, each of which was stopped at the same cost. The buying rule takes the form of optimizing

$$Pr(NMCS \leq CSO)$$

where CSO represents the cannibalization support objective. Think of the CSC as the number of "cann birds" (cannibalized aircraft) you are willing to accept. (It is important to distinguish this parameter from the DSO. The DSO remains as our stopping rule parameter -- the number of aircraft we are willing to allow down for supply problems on the day of interest.) It is not inconsistent to assign different values to the DSO and CSO. For example,

DSO = 6 and CSO = 2 means that while we may accept six aircraft down for supply, we want to buy stock as if there are only two cann birds. In other words, four planes could be fixed within a reasonable amount of time and two planes would be full of holes.

Note that when the CSO is 6, the ENMCS is smaller than under the pipeline floor method, but more cannibalizations (more MICAPs) occur. However, as we lower the value of CSO we reduce cannibalizations, which suggests an alternate method for controlling for cannibalizations -- a method that, unlike the pipeline floor, is sensitive to cost. We return to this point later.

STABILITY: COMPARISON OF KIT COST

Data Base	F-15C		F-16C	
	With Floor	Without Floor	With Floor	Without Floor
87M D029	\$48.3M	\$40.3M	\$33.1M	\$34.8M
88M D029	\$38.9M	\$31.1M	\$32.1M	\$34.2M
Difference	- 19.5%	- 22.8%	- 3.0%	- 1.7%

STABILITY: COMPARISON OF KIT COST

Another reason given for pipeline floors is the belief that the floor policy reduces the instability in kit requirements. By instability, we mean the variation in range, depth, and cost of the kits from year to year caused by new stock numbers and changing rates and factors.

This table compares, for two weapon systems, the same kit serial number across two different D029 data bases. We find that

the floor itself has little to do with the instability. The F-15C kit is unstable -- with or without floor -- and the F-16C is relatively stable -- with or without floor. After all, changing rates and factors imply instability in the floor quantities themselves.

Stability is a valid concern. Significant variations in requirements play havoc with management systems at AFLC. We believe, however, the pipeline floor policy contributes little to stability.

IMPLEMENTATION: PIPELINE FLOOR

- Buying rule could explicitly constrain cannibalizations
 - Choose number of allowable cannibals
 - Easy to implement
- "Partial" cannibalization model
 - Need flag for hard to cannibalize items
 - Buy floor for items that are hard to cannibalize
 - Easy to implement with item switch

IMPLEMENTATION: PIPELINE FLOOR

Changing the buying rule to explicitly constrain cannibalization actions would be cost-efficient. Implementing such a rule would be straightforward. The Air Force would not have to change policy since the specific marginal analysis technique is not discussed in any existing policy.

If the buying rule were changed, the pipeline floor policy could be changed. It could be retained only for those items for which

cannibalization is difficult. Work is already underway to develop a "partial" cannibalization enhancement to the ASM, which would allow some items to be flagged as hard to cannibalize; the modified marginal analysis would recognize this distinction, but would still strive for least-cost solutions.

SUMMARY: PIPELINE FLOOR

- Value of the floor
 - Some protection for the surge
 - Some protection against cannibalization actions
- Drawbacks to the floor
 - Inconsistent with DSO
 - High cost
 - Not used in budget allocation
- Alternative floor policies
 - Drop the floor in favor of explicit cannibalization constraint
 - Item exceptions (hard to cannibalize, high QPA)

SUMMARY: PIPELINE FLOOR

While the Air Force has some valid reasons for its current floor policy, those reasons are offset by the high cost and the resulting inconsistency in the philosophy of cannibalization. An additional inconsistency occurs between the requirements computation, for which a floor is imposed, and the way we actually spend dollars, without a floor.

If we wish to explicitly constrain the number of cannibalization actions (such constraint would require setting another parameter),

the ASM can certainly build a kit with such a constraint explicitly imposed. While such a change would lead to changes in both the range and depth of kits, this would be a one-time variation that is unlikely to lead to persistent instability in item requirements.

Item exceptions to the no-floor policy could be made. Such exceptions would be desirable for items that are hard to cannibalize and also for items that have both a high quantity per application (QPA) and low procurement cost.

ISSUE 2: SETTING THE DSO

- **Policy definition**
 - **Stopping rule – ENMCS tolerance for Day 30**
 - **Interpreted as a percentage of PAA (25% for TAC)**
- **What about other days?**
 - **Day 7 ?**
 - **Day 60, Day 180 ?**
- **Factors in setting the DSO**
 - **Empirical data**
 - **The threat and tactics**
 - **Credibility**

ISSUE 2: SETTING THE DSO

We have noted that the DSO is used today as a parameter for both the buying rule and the stopping rule of marginal analysis. Let us agree that the DSO target represents the number (or percentage, more generally) of NMCS aircraft that we will *tolerate* on Day 30. The current value of 6 per 24 PAA is being treated as a goal of 25 percent that is applicable to any size squadron. For example, an 18 PAA should have a DSO of 4.5. Note that, unlike Dyna-METRIC, the ASM allows a fractional DSO, which is particularly important for small PAAs.

According to current policy, the DSO is meaningful only on Day 30. Today's kit requirement technique pays no explicit attention to our capability to fight the entire scenario.

A mixture of three factors influences the decision as to the proper DSO:

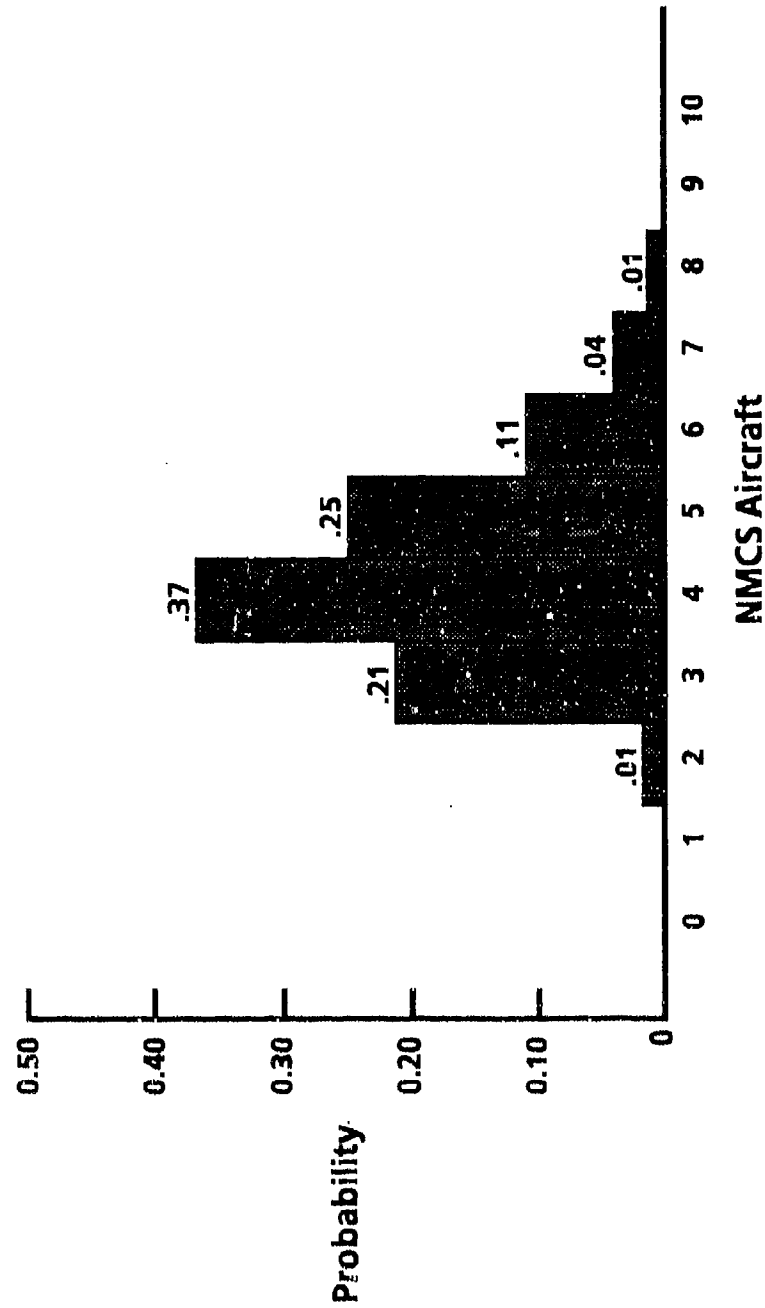
- First, empirical evidence as to the number of aircraft that will be down for reasons other than supply. Field exercises

at Eglin AFB, Florida, in the late 1970s led to the original DSO value of four. It was observed that typically four aircraft were NMC for reasons other than supply.

- Second, some notion of the threat -- how many aircraft do we need to win? The number of required aircraft depends on daily sortie targets, as well as the massing (the number of aircraft simultaneously in the air) employed by the commander. Tactics and the operations tempo should play a role in setting the operational requirements.
- Third, the approach we take to setting the DSO should be credible and defensible. This means that the DSO should reflect some of the operational concerns listed above and, at the same time, yield kit costs that are affordable.

The first step to a defensible DSO is paying attention to our capability to fight on days other than Day 30.

TODAY'S KIT: PERFORMANCE ON DAY 7



ENMCS = 4.4, $\Pr(\text{NMCS} \leq 4) = 0.59$

TODAY'S KIT: PERFORMANCE ON DAY 7

This histogram depicts how well the current kit for the F-15C performs on Day 7 of the wartime tasking. (We pick Day 7 because it represents the last day of the surge period.) With a fully funded kit, we expect to have 4.4 aircraft down because of supply on Day 7. The probability of 5 NMCS is 0.25, of 6 NMCS is 0.11, etc. Careful scrutiny of the utilization rates for F-15Cs together with their maximum turn rates reveals we need an absolute minimum of 15 FMC aircraft ($DSO = 5$) in order to achieve the WMP sortie goals. TAC has expressed a view that 20 FMC aircraft ($DSO = 4$) are required to fly an 18-turn-18 employment (two aircraft spares are needed for maintenance downtime or ground aborts). This

histogram shows that today's kit may not meet the Day 7 sortie goal because there is only a 59 percent chance of four or fewer aircraft NMCS on Day 7.

This failure is partly a result of our improved optimization techniques. In the past, our inability to properly handle the indeterminate trade-off resulted in some "fat" in the kit that, inadvertently, provided some additional protection during the surge period. That problem could be addressed by stating our NMCS objectives not just on Day 30 but throughout the scenario.

ASM CROSS-LINKER

- Cross-Linker Technique
 - ▶ Considers more than one objective function
 - ▶ Finds least cost of achieving all objectives simultaneously
- Application to WRSK
 - ▶ Two objectives: DSO = 4 on Day 7, DSO = 6 on Day 30
 - ▶ Find minimal cost such that

$$\Pr(\text{NMCS} \leq 4) = 0.80 \text{ on Day 7}$$

and

$$\Pr(\text{NMCS} \leq 6) = 0.80 \text{ on Day 30}$$

ASM CROSS-LINKER

We have developed a mathematical technique for finding optimal solutions to more than one objective simultaneously. Previously, the DSO has been defined only for Day 30 for two reasons:

1. The belief that adequate performance on Day 30 implies adequate performance throughout the scenario.
2. The lack of any technique for looking at more than 1 day.

We have documented the error in Reason 1 and the Cross-Linker provides the solution to Reason 2. Now, let's look at the Cross-Linker results of achieving these two objectives:

$$Pr(NMCS \leq 4) \text{ on Day 7}$$

and

$$Pr(NMCS \leq 6) \text{ on Day 30.}$$

CROSS-LINKER RESULTS

Option	Cost (millions)	Day 30			Day 7		
		Confidence (DSO = 6)	ENM/CS	MICAPs	Confidence (DSO = 4)	ENMCS	MICAPs
Today's Kit	\$38.9	80%	5.6	234	59%	4.4	76
Dual DSOs	\$42.9	80%	5.6	232	80%	3.7	64

CROSS-LINKER RESULTS

We have observed how a kit computed under the current policy may not be able to meet the sortie goal of the first week of the planned scenario. Here is our dual DSO problem. Suppose we agree that we need at least 20 aircraft on Day 7 ($DSO=4$) in addition to a requirement of 18 aircraft on Day 30. The ASM can build, as this table shows, a kit that will simultaneously achieve both objectives, to an 80 percent confidence, for a cost of \$42.9 million. (Recall that today's kit optimized for Day 30 only was budgeted for \$38.9 million.)

This chart illustrates the variable support objective concept. The cost increase is modest; concern about it, however, should be tempered by two observations:

- The increased cost of a Day 7 DSO could be offset by an increase in the DSO for Day 30. It is generally agreed that

the planning scenario requires less than 75 percent of the aircraft beyond the surge period. A typical scenario of 14-turn-12 for a total of 26 sorties suggests that we need about 16 aircraft, instead of 18, on Day 30 — this would allow 2 spare aircraft for ground aborts and downtime due to maintenance.

- This table was built using the pipeline quantities as a floor. We might have a more affordable kit that is better able to fight by adopting the variable support objective concept together with a modified approach to the current floor policy.

IMPLEMENTATION: MULTIPLE DSOs

- **Cross-Linker**
 - **Implemented in ASM 2.0 (PC version) for 2 days**
 - **Work to convert to REALM**
- **Multiple (more than 2) DSOs not yet implemented**

IMPLEMENTATION: MULTIPLE DSOs

The Cross-Linker for optimizing 2 days simultaneously has already been implemented in the personal computer (PC) version of the ASM. Since the PC version of the Cross-Linker is highly interactive, converting to the production batch environment of WSMIS/REALM poses some challenges. Cross-linking more than 2 days has not yet been implemented. While work remains to be done, no insurmountable difficulties are expected.

We have demonstrated the ability to deal with variable DSOs. What we really need, though, is a credible way of setting and defending DSO targets. Unfortunately, the DSO, by definition, focuses on the number of aircraft allowed *down*. We will approach the problem by thinking about the number of aircraft we need *up* to achieve our objectives.

SETTING DEFENSIBLE DSOs

- **Today's DSO**
 - **Inconsistent with cannibalization policy**
 - **Difficult to defend**
- **Recent Defense Management Review Study**
 - **Considered attrition**
 - **Selected DSOs using minimum FMC**
 - **Forced review of pipeline floor**

SETTING DEFENSIBLE DSOs

The choice of the DSO values drives the cost of the kit. Our inability to set and defend the DSO as an operational requirement has resulted in too much attention to the relationship between the DSO and cost.

The DSO is used as an ENMCS target. Since the ENMCS is calculated assuming maximum cannibalization, DSO used this way is an apparent contradiction to the stated policy that cannibalization is not to be considered a source of supply. Moreover, the current DSO of six for all tactical aircraft is difficult to defend.

Why should all of these aircraft require the same support objective, given different tasking and utilization rates?

What has been lacking is a coherent discussion of the number of aircraft we need to meet our sortie objectives. A recent analysis conducted by the Air Staff in response to a Defense Management Review considered this question. The DMR raised many issues including the use of attrition. Additionally, a new minimum FMC approach was developed. This approach forced a review of the pipeline policy. We now explain the new method to setting DSOs.

AN APPROACH BASED ON MINIMUM FMC

- Requirement (hypothetical)
 - 66 sorties/day for surge, 36 thereafter
 - Maximum turn rate = 3.5
- Implications
 - Minimum FMC = $66/3.5 = 19$ for Day 7, $36/3.5 = 11$ for Day 30
 - Therefore, DSO = 5 for Day 7, 13 for Day 30
- May need modification
 - Alert aircraft
 - Spares for maintenance downtime

AN APPROACH BASED ON MINIMUM FMC

Suppose our F-15C squadron has been tasked at 66 sorties per day for the 7-day surge and 56 sorties per day thereafter. Further, suppose the high surge rate is 3.5 throughout the scenario. The high surge rate is used as the *maximum* number of turns that can be performed on an aircraft, on average, per day. These parameters are hypothetical -- the true values appearing by Mission/Design Series (MDS) and theater appear in the WMP but are classified.

The minimum FMC approach computes the minimum number of aircraft, assuming the high surge rates, needed to fly the

program. This logic leads to the conclusion that we only need 19 aircraft FMC ($DSO = 5$) for the surge and 11 aircraft FMC ($DSO = 13$) on Day 30. This approach ignores any considerations related to tactics. It ignores massing (requiring flights of four, for example) and it assumes that the high surge rates can be maintained throughout the conflict. Nonetheless, let's look at the requirement for such a kit.

MINIMUM FMC: AN EXAMPLE

Option	Cost (millions)	Day 30			Day 7		
		Confidence Min. FMC = 11	FMC	MICAPs	Confidence Min. FMC = 19	FMC	MICAPs
Today's Kit	\$38.9	100%	18.4	234	84%	19.6	76
Floor Only	\$33.9	97%	15.7	330	66%	18.8	99
Min. FMC*	\$24.3	80%	13.0	651	80%	19.3	223

* Minimum FMC approach buys to 80% confidence that FMC = 19 and 11 on Days 7 and 30, respectively. No floor was included. Notional utilization rates were used.

MINIMUM FMC: AN EXAMPLE

This table compares a kit built with the minimum FMC of 19 and 11 on Days 7 and 30, respectively, to either today's kit or a floor only kit. This kit results in a "saving" of 13 percent from today's kit. Of course, our cannibalization actions have skyrocketed. Our observation at the second and third Coronet Warrior exercises was that there was additional cannibalization capacity in terms of manpower. However, projecting the number of cannibalizations that are feasible in a real wartime environment is difficult.

Care must be taken in setting the DSO. The minimum FMC approach described here ignores the aircraft employment -- the massing requirement. Moreover, blind implementation of this approach can result in totally unrealistic cannibalization actions.

The choice of confidence-level target is related to the DSO. If the DSO is determined on a minimum FMC basis, then we need a 100 percent confidence level. Put another way, a kit bought to an 80 percent confidence level has a 20 percent chance that the number of FMC aircraft is less than the minimum needed. Consequently, the kit will not fly all of its sorties. This is undesirable. On the other hand, buying to a 100 percent confidence level is prohibitively expensive.

It may be necessary to adjust the minimum FMC to be an acceptable target as an *average*. Otherwise, the definition of DSO must be changed and implementation problems must be addressed.

SUMMARY: SETTING THE DSO

- A full kit may not meet the surge sortie goal
- Need multiple DSOs
 - ASM has the capability to optimize 2 days
 - Concept approved by AFSWP
- Need policy decisions on DSO
 - Defensible
 - Operator input

SUMMARY: SETTING THE DSO

We have seen that today's policy, based on a single DSO for Day 30, can fail to provide the necessary capability for the surge. The ASM is capable of optimizing across different targets for different days -- all that is needed is some policy direction on setting the DSO values.

This direction should be provided by the operator community, with feedback from the logisticians as to the effects of various options.

We have also seen that a discussion of DSOs always involves a discussion of pipeline floors, confidence levels, and cannibalization policies. We return to that point after examining one last issue -- the determination of the most appropriate stopping rule.

ISSUE 3: SETTING THE TARGET

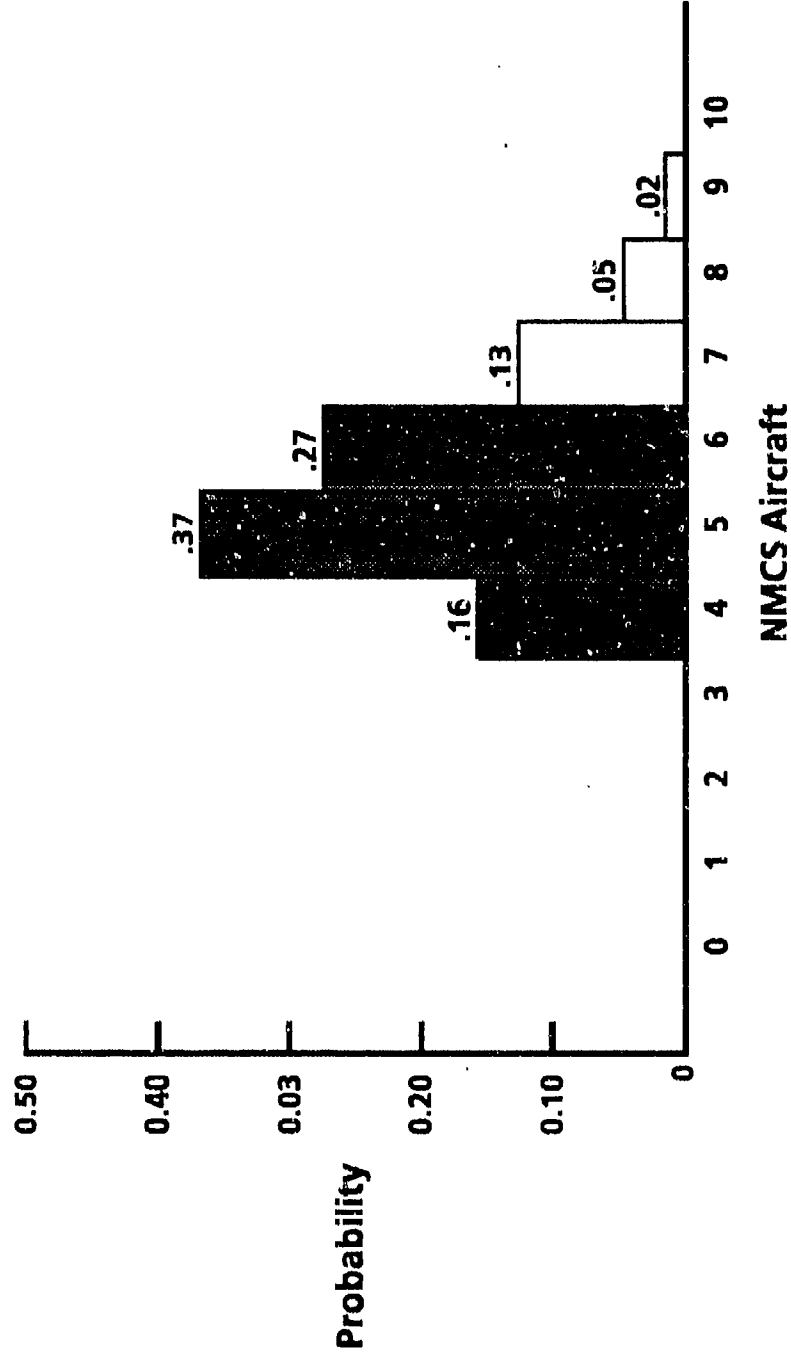
- Today's stopping rule: confidence level
 - ▶ Stop when $\Pr(\text{NMCS} \leq 6) = 0.80$
 - ▶ Not guided by policy
 - ▶ Empirically, 0.80 achieves (usually) DSO
- Alternative stopping rule: ENMCS
 - ▶ Stop when $\text{ENMCS} \leq \text{DSO}$
 - ▶ Consistent with today's policy
 - ▶ Approved by AFSWP

ISSUE 3: SETTING THE TARGET

The question is, "When do we have enough spares?" We have noted that the marginal analysis technique used by Dyna-METRIC requires a stopping rule based upon the confidence level. Current REALM implementation calls for a 0.86 target confidence level for WRSK. (There has been some discussion of a 0.95 target for BLSS.) We have observed that, empirically, a 0.80 target usually results in an ENMCS value that is less than or equal to the DSO. For instance, the F-15C kit documented earlier showed that the 80 percent confidence corresponded to an ENMCS of 5.6.

The ASM can produce tables or curves that completely describe the relationship among kit cost, confidence level, and ENMCS. In particular, it is possible to stop when the ENMCS hits the DSO target, which is actually consistent with today's policy. This proposal was approved by the June 1989 AFSWP and has been implemented in the ASM. We examine the results for our F-15C kit.

TODAY'S KIT: NMCS AIRCRAFT ON DAY 30



ENMCS = 5.6, $\Pr(\text{NMCS} \leq 6) = 0.80$

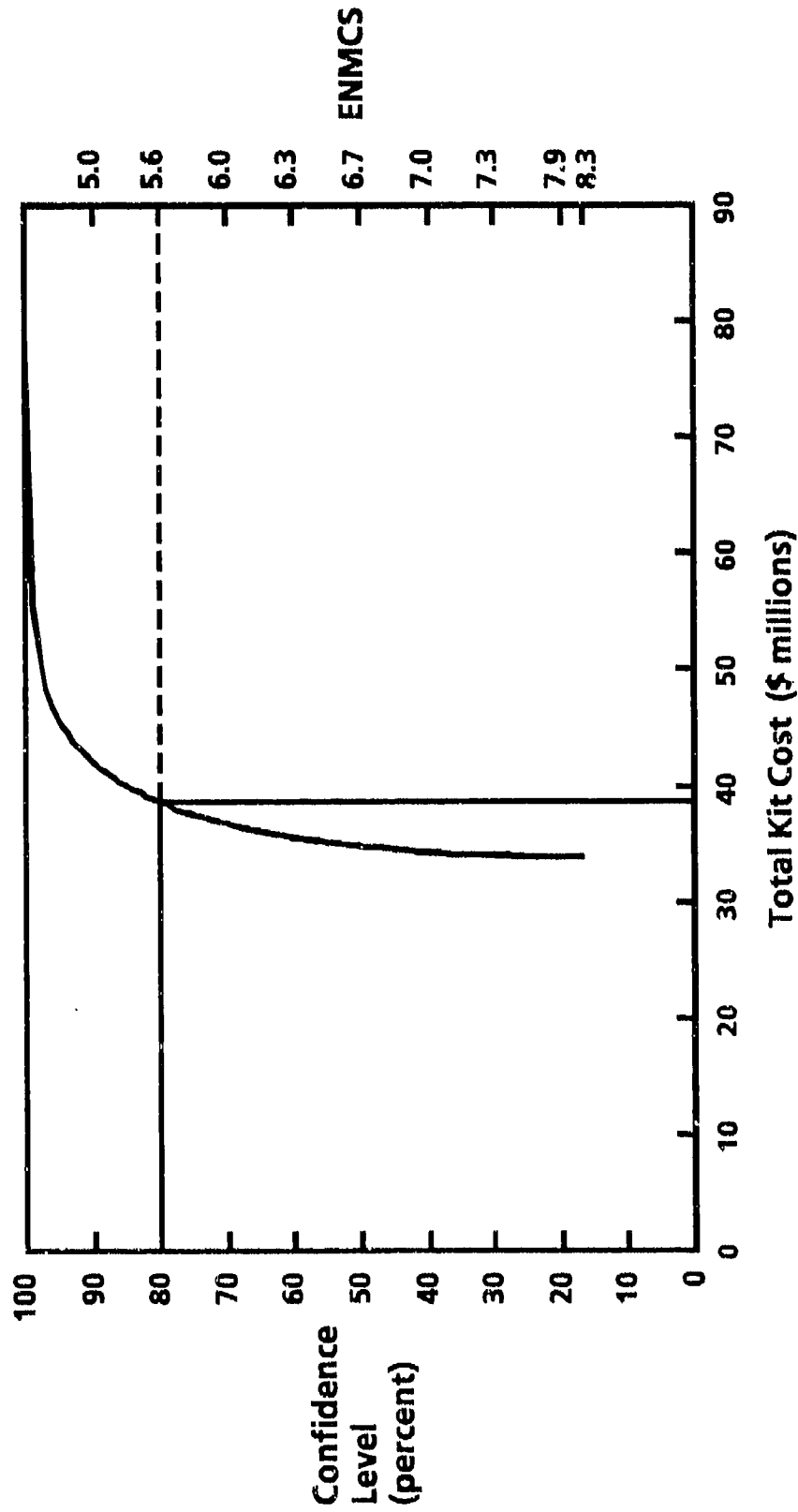
TODAY'S KIT: NMCS AIRCRAFT ON DAY 30

This histogram describes what we actually get, in terms of available F-15C aircraft, with the ASM-built kit of \$38.9 million. As noted earlier, the kit was built to provide 0.80 confidence. This histogram shows the entire distribution of NMCS aircraft. We have an average NMCS of 5.6, and the single most likely number of NMCS aircraft is 5 (with a 0.37 probability). What does this histogram say about the adequacy of our kit? The answer depends upon how many aircraft we need to fight on Day 30. We can fly the typical Day 30 sortie schedule with 8 aircraft, and we have almost a

100 percent probability of having 8 aircraft (16 or fewer down because of supply). Thus, ~~this~~ it is more than adequate from the Day 30 perspective.

This histogram emphasizes that the number of NMCS aircraft, like component demand and backorders, is a random variable. We have shaded the confidence-level portion of the histogram. Why is 0.80 the appropriate target?

COST VERSUS CONFIDENCE (DAY 30)



COST VERSUS CONFIDENCE (DAY 30)

The ASM produces an entire curve of confidence level as a function of kit cost. The current Air Force policy is to stop buying when the confidence level hits 0.80. In the example shown here, a 0.80 confidence level corresponds to an ENMCS of 5.6. (Recall that the real objective is to achieve an ENMCS of 6 or lower.) This curve, then, implies that we could achieve an ENMCS of 6 for less

than \$38.9 million. Of course, having 5.6 aircraft down for supply is better than having 6 aircraft down. The point here is that we now have the capability of implementing the existing policy rather than approximating it.

The next chart suggests an alternative stopping rule.

COST, CONFIDENCE, AND ENMCS RELATIONSHIP

ASM OUTPUT FLOOR QUANTITIES INCLUDED

Confidence (DSO = 6)	Cost (\$ millions)	ENMCS
72%	\$37.0	6.0
80%	\$38.9	5.6

Todays
Stopping
Rule

Alternative
Stopping
Rule

COST, CONFIDENCE, AND ENMCS RELATIONSHIP

This shows the relationship of our three variables for the F-15C (with the pipeline floor minimum quantities). The table indicates that, instead of buying an 80 percent kit for \$38.9 million, we could buy an ENMCS = 6 kit for \$37.0 million.

Our objective is not particularly to save money (you get what you pay for in terms of ENMCS) but to point out that with the AGM,

we do not need a confidence-level target, and dropping the confidence-level target would certainly eliminate a lot of confusion. More to the point, however, we believe this approach is in the spirit of the existing policy.

IMPLEMENTATION: SETTING THE TARGET

- ENMCS target implemented in ASM 2.0 (PC version)
- Conversion to production REALM straightforward

IMPLEMENTATION: SETTING THE TARGET

The use of an ENMCS target as a stopping rule has already been implemented in the PC version of the ASM. Converting to the production batch environment of WSMIS/REALM is not difficult.

SUMMARY: SETTING THE TARGET

- Confidence-level target driven by limitations of Dyna-METRIC
- Target ENMCS
 - › Consistent with policy
 - › Could be in REALM when approved
 - › Concept approved by AFSWP
- Modify minimum FMC to represent *average* target

SUMMARY: SETTING THE TARGET

The need for having a confidence-level target arose from the limitations in the Dyna-METRIC model. Since the ASM does not have those limitations, we recommend that confidence-level targets be dropped. In their stead, we propose that marginal analysis should stop whenever the ENMCS falls below the DSO value.

Implementation of this recommendation will result in an implicit confidence level that is usually, but not always, less than the current 0.80 standard.

This recommendation assumes that the approved DSO is acceptable as an *average* NMCS target. If the minimum FMC approach to setting the target is used, the target should be adjusted so that it can be used this way. For instance, if it is determined that 18 aircraft are needed as an *absolute* minimum to meet the sortie goals of a particular day, it is logical to conclude that 18 aircraft are needed *with certainty*. This could be difficult to implement -- it may be better to achieve 20 FMC aircraft *on average* rather than 18 FMC *with certainty*.

EXAMPLE: COMBINED EFFECTS

- Drop floor
- Buy with cannibalization constraint
- Stop when $ENMCS \leq DSO$
 - $DSO = 4$ for Day 7
 - $DSO = 8$ for Day 30

EXAMPLE: COMBINED EFFECTS

We illustrate the combined effects of changing our buying and stopping rules. Suppose that the operators have defined the requirement this way:

- *Stopping Rule*

- ▶ We need 20 aircraft on Day 7 (18-turn-16 + 2 spares).
- ▶ We need 16 aircraft on Day 30 (14-turn-2 + 2 spares).

- *Buying Rule*

- ▶ We have an objective of no more than 2 cann birds on Day 7; i.e., $CSO = 2$ on Day 7.

- ▶ We have an objective of no more than 4 cann birds on Day 30; i.e., $CSO = 4$ on Day 30.

Then we implement by dropping the pipeline floor, buying Day 7 with $Pr(NMCS \leq 2)$ rule, buying Day 30 with $Pr(NMCS \leq 4)$ rule, cross-linking the result, and stopping when $ENMCS = 4$ and 8 on Days 7 and 30, respectively.

The results are shown on the next chart.

RESULTS: COMBINED EFFECTS

Option	Cost (millions)	Day 30		Day 7	
		ENMCS	MICAPs	ENMCS	MICAPs
Today's Kit	\$38.9	5.6	234	4.4	76
Alternative Kit	\$31.6	8.0	362	4.0	105

- Alternative Kit – Cross-Linker for Days 7 and 30 with
 - ▶ Cannibalization constraint
 - ▶ Stop Rule: ENMCS = 4 on Day 7
ENMCS = 8 on Day 30

RESULTS: COMBINED EFFECTS

The last line displays the performance of a kit computed as we just described. In this case, we chose a DSO of 4 on Day 7 and 8 on Day 30 but with buying rule parameters of 2 and 4, respectively. This kit meets the operational objectives as we have defined them for 19 percent less cost than today's kit.

The real message: we have a new technique that affords the opportunity to take a fresh look at our existing spares policies.

SUMMARY OF ISSUES

- Consider modifications to the floor policy
 - ▶ Clarify cannibalization policy
 - ▶ Item exceptions
- Adopt multiple DSOs
- Use DSOs as ENMCS targets

SUMMARY OF ISSUES

We believe these three issues are interrelated and that policy decisions should be treated as a package. We recommend that the Air Force take the following actions:

- Consider modifications to the floor policy. These modifications involve agreeing on some consistent policy concerning cannibalizations. A cannibalization constraint could be imposed if necessary. Item exceptions could also be made.
- Adopt a multiple DSO concept. For a typical 30-day scenario, this new concept would require establishing a DSO for Day 7. Achieving the desired performance levels on Day 7 and Day 30 would likely provide adequate performance for all other days. [While the support objectives

are under study, it would also be wise to set DSOs for Day 60 and Day 180. Those DSOs are needed for the subsequent Follow-On Spares Kit (FOSK) and Other War Reserve Materiel (OWRM) computations.]

- Eliminate confidence-level targets altogether, and use the DSO as the ENMCS goal.

These three recommendations should be considered together. For instance, reducing the floor quantities without adopting variable support objectives would make our surge capability even worse. There may be other issues that should be tied in as well; the impact of attrition is one that is undergoing current scrutiny.

ISSUE 4: INCLUDING ATTRITION IN WRSK

- **Air Force Audit Agency Study**
 - **WMP-5 calls for use of attrition rates**
 - **Analysis of effects, using Dyna-METRIC 4.4**
- **Do we necessarily want attrited flying hours?**
- **Setting the DSO with attrition**

ISSUE 4: INCLUDING ATTRITION IN WRSK

A recent Air Force Audit Agency (AFAA) study^{*} criticized the Air Force for failing to include the attrition factors specified in the WMP in the WRSK computations. The AFAA used Dyna-METRIC to recompute and found that, with some exceptions, the kits with attrition would generally cost less than kits computed without attrition. This effect is predicated upon the peculiar way we define resource requirements in the WMP. Instead of having a certain total sortie goal, we base our required resources on an aircraft utilization rate. If, for instance, we plan a utilization of 2 sorties per aircraft per day, our loss of an aircraft to attrition on Day 1 would result in $29 \times 2 = 58$ fewer sorties over the remaining 29 days. Consequently, we have fewer demands upon supply and thus a lower cost. This whole approach is troublesome. Shouldn't we pay some attention to the war as we would likely fight it? Put another way: isn't it likely that we would fly the aircraft we have harder to make up for attrition?

^{*}Air Force Audit Agency Draft Report of Audit, *Computation of Aircraft Wartime Spares Requirements(U)* (Project 8126121), 17 Feb 1989.

Another thorny problem in implementing attrition is how to set the DSO. If we agree that the DSO is expressed as a percentage (25 percent, for instance), does that mean that, just as we would spare for 18 out of 24 aircraft without attrition, we want only enough spares to support 9 of 12 surviving (after attrition) aircraft? The minimum FMC approach to setting the DSO adapts well to the attrition issue. Given attrition rates and fillers, we must determine the sortie schedule we would fly and the minimum number of aircraft required to meet that schedule.

Finally, to repeat our technology and policy theme, we should be careful that our models implement attrition in the way we intend. Our preliminary analysis suggests, for example, that Dyna-METRIC, while it tries to compute attrited sorties as described above, actually does so incorrectly. Again, policy makers, as well as analysts, should be concerned with the way policy gets implemented.

TODAY'S KIT: WITH ATTRITED SORTIES

Option	Cost (millions)	Day 30				Day 7	
		Conf.	DSO	ENMCS	MICAPs	ENMCS	MICAPs
Today's Kit	\$38.9	80%	6	5.6	234	4.4	76
Today's Kit with attrition	\$35.3	80%	4	3.8	129	3.7	56

TODAY'S KIT: WITH ATTRITED SORTIES

We show the effects of attrition upon today's kit. The attrition calculation was based upon a $DSO = 25$ percent of the nonattrited aircraft on Day 30. In this case, since 16 aircraft remained, the DSO was set to 4. All other parameters were left alone -- the pipeline floor was included, although the cost of the floor was reduced by 30 percent because of the reduction in flying hours. A 9 percent reduction in kit cost is typical of the AFAA results.

ALTERNATIVE KIT: WITH ATTRITED SORTIES

Option	Cost (millions)	Day 30			Day 7		
		DSO	ENMCS	MICAPs	DSO	ENMCS	MICAPs
Alternative Kit	\$31.6	8	8.0	392	4	4.1	105
Alternative Kit with attrition	\$56.4	2	1.9	48	2	2.0	23

ALTERNATIVE KIT: WITH ATTRITED SORTIES

This chart shows the effects of attrition upon the alternative kit we described earlier -- a kit built without the floor but with dual DSOs and cannibalization constraints. Since the Air Force has given no guidance at all about setting DSOs with the effects of attrition, we set the target at 14 FMC out of 16 nonattrited aircraft for both Days 7 and 30. Our (somewhat arbitrary) planning scenario calls for a schedule of 12-turn-12 (with two aircraft for ground aborts and maintenance downtime) on both days. This

scenario will allow a DSO of 2. Attrition causes the cost of the kit to increase enormously. The point is that attrition can cause the kit cost to increase or decrease, depending on how we define the operational requirements. This uncertainty argues for treating attrition in a way that provides maximum flexibility to the squadron commander. The details of how to do this are still under development.

IMPLEMENTATION: INCLUDING ATTRITION

- Data requirements
 - DSO as a function of attrition
 - Squadron-specific rates and fillers
- Interface with WMP-5

IMPLEMENTATION: INCLUDING ATTRITION

No particular modeling capability must be added to deal with attrition, but attrition rates and filler information must be provided at the squadron level for contingency kits. It could be difficult to choose rates that make sense for the generic buy kits that are used for budgeting. Whatever data are appropriate must be fed to WSMIS/REALM via an interface with the WMP-5 data base. This is not a difficult process.

Modeling attrition is not as difficult as determining the appropriate attrition parameters. The most serious impediment to including attrition is the decision about how we would fight with fewer aircraft.

SUMMARY: INCLUDING ATTRITION

- **Effects of attrition**
 - **Attrited sorties reduce the requirement**
 - **Reduced DSOs increase the requirement**
- **Attrition policy – How would we fly?**

SUMMARY: INCLUDING ATTRITION

Putting attrition into the kit computation can cause the cost to go up or down: using attrited sorties reduces the cost while reducing the DSO increases the cost. To attrit the sortie requirements drives the pipeline and resulting kit cost downward. To make up sorties by flying harder, thereby reducing the DSO, increases the kit cost. Once these operational decisions are made, existing computational software can determine the kit requirement.

SUMMARY

- **Conclusions**
 - ▶ **Pipeline floors**
 - ☐ Expensive
 - ☐ Inefficient cannibalization control
 - ☐ There are alternative strategies for constraining cannibalizations
 - ▶ **DSOs**
 - ☐ Should be driven by operational requirements
 - ☐ Should vary by day
 - ▶ **Confidence-level target**
 - ☐ Not guided by policy
 - ☐ Not needed with new technology
- **Potential for improved capability and credibility**

SUMMARY

We have shown that the pipeline floor is an expensive and not particularly efficient way of controlling cannibalizations. Kit stability, while deserving study, seems to be little affected by the pipeline floor.

DSOs should be set based upon operator answers to the question, "How many aircraft do we need?" They should also vary by day since we have seen that a kit built to Day 30 objectives may not fly the surge. The Cross-Linker technique of the ASM provides the ability to build kits that can meet multiple-day objectives.

Finally, no confidence-level target is needed. This has been confusing; it is not guided by policy and was required only by the

limitations of Dyna-METRIC software. The new techniques offered by the ASM offers a kit sized on an ENMCS target equal to the DSO. This permits implementation of the existing policy.

We believe that the spares policy can be refined so that it will result in a greater operational capability and more efficient use of Air Force resources. We can refine it by modifying the pipeline floor policy, dealing explicitly with cannibalization constraints, and defining DSO targets throughout the scenario that are determined by operational requirements. This approach will lead to greater capability and at the same time increase the credibility of the requirement process.